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Informal Report

SURVEY OF OPERATION AND MAINTENANCE-RELATED MATERIALS NEEDS IN GEOTHERMAL POWER PLANTS

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SUMMARY

A survey was conducted to determine operation and maintenance (O&M)-related materials needs in geothermal power plants and to identify future research and development to address these needs. A total of 44 questionnaires was mailed to geothermal plant operators and industry consultants. The response rate was 54%. The participants were asked to describe type and frequency of materials problems, strategies currently used to mitigate such problems, barriers to using new or alternative materials and technologies, sources of information and give their views research and development priorities. A wide range of opinions was obtained, reflecting each individual respondent's perspective and the site-specific nature of some problems. However, the consensus is that corrosion and scaling remain major issues and that components requiring performance improvements include pipelines, well casing, turbines, heat exchangers, condensers, valves and cooling towers. It is recommended that appropriate research and development continue to be directed at reducing O&M costs associated with materials failure or inadequate service. There should be a balance between optimizing existing materials through better design and understanding of behaviour in geothermal environments and development of new materials. Life extension of existing equipment, service life prediction, education of plant personnel in materials and methods for mitigating corrosion, and improvements in inhibitors and biocides would also be beneficial.

ACKNOWLEDGEMENTS

This work was funded by the U.S. Department of Energy/Office of Geothermal Technologies. Thanks are due to Mr. Ray LaSala for his support of this activity. In addition, the assistance with making contacts for the survey given by Ms. Perle Dorr, Mr. Larry Kukacka and Dr. John Rowley is much appreciated. Finally, all of the survey participants are thanked for their time, cooperation and valuable suggestions.

INTRODUCTION

Increasing the competitiveness of geothermal electrical power energy requires reduction of costs ranging from exploration and drilling to plant operation and maintenance (O&M). Brookhaven's Geothermal Materials Program focuses on research and development of durable, economic materials for use in geothermal environments. Corrosion and scaling of power plant equipment, degradation of well cements and lost circulation during drilling are examples of typical problems encountered in the utilization of geothermal energy that are addressed in Brookhaven's activities. In order to best serve the geothermal industry, Brookhaven continually seeks input and direction to prioritize materials research and thereby improve the efficiency and economics of energy conversion.

At the request of our Program Manager from the Department of Energy/Office of Geothermal Technologies, Mr. Ray LaSala, Brookhaven conducted a survey to identify:

- O&M-related materials needs in geothermal power plants.
- Means of improving materials performance and reliability.
- Means of reducing O&M costs.
- Future research priorities.

A list of potential participants was compiled with the assistance of Ms. Perle Dorr (Geothermal Energy Association), Mr. Larry Kukacka (BNL-retired) and Dr. John Rowley (Pajarito Enterprises). A notice was also placed in the DOE insert of the Geothermal Bulletin inviting industry members to participate. The total number of responses was 24 out of 44 representing a return rate of 54%. In addition to the U.S., responses were also received from New Zealand, The Philippines, Costa Rica, Mexico and Indonesia. A cross-section of participants was sought in order to obtain a variety of opinions. The respondents included personnel responsible for geothermal plant maintenance and management as well as consultants. In order to avoid potential bias, participants with or seeking DOE funding were excluded. The identity of the respondents is being held confidential.

When analyzing the results it must be kept in mind that the sample is relatively small. In addition, the responses depend on the individual's particular role and the location of the power plant. Different resources have different brine chemistry and temperature. Other variables, such as plant age, also affect the type and severity of problems encountered. Hence, some problems, or their impact, may be site-specific.

The questionnaire is presented in Appendix A. Participants were asked to state their role or interest in O&M of geothermal power plants, estimate the percentage of plant operating costs that are a direct result of materials problems and answer questions on the frequency of problems encountered and the current means of addressing these. Participants were also requested to identify their sources of information on materials and list what they see as future research needs.

PAST RELEVANT STUDIES

Reports on materials needs compiled in the 1980s were reviewed to form a baseline. Recent comments on research priorities and O&M related materials problems were examined from sources such as GEA workshops, publications in the Geothermal Resources Council Transactions and other literature.

In 1981 the National Materials Advisory Board issued a report titled "Materials Needs for the Utilization of Geothermal Energy". This report included materials needs in drilling and completion, in addition to production, utilization and reinjection. Specific long-range R&D projects that were identified and are relevant to the current survey include:

- Preparation and properties of coatings, especially on pipes, to improve corrosion and erosion resistance
- The development of new non-metallic solids including ceramics, high-temperature elastomers, and insulation such as solid foams and composite materials
- The development of new designs utilizing existing as well as new materials
- The study of nucleation and growth mechanisms of scales and surface abrasion
- The development of new cements, cement properties (such as high temperature rheology and phase chemistry), and cementing adhesion
- Research on the utilization and elimination of process wastes
- The development of non-destructive techniques for monitoring continuing degradation and/or catastrophic failures of materials and components
- Non-destructive testing of coatings and field repair of large area coatings
- The development of cheaper, high thermal conductivity, corrosion resistant materials for condensers and cooling towers (both wet and dry types)
- The education of materials engineers in the problems of geothermal energy

The National Research Council published a report in 1987 titled "Geothermal Energy Technology: Issues, R&D Needs, and Cooperative Arrangements". Needs identified in this report include:

- Corrosion prevention techniques (e.g., inhibitors, anodic and cathodic protection)

- Corrosion resistant materials
- Elastomer lined casings
- Materials for heat exchanger tubing and well casing
- High temperature elastomers for dynamic seals

Other literature provides insight on materials performance in geothermal environments. ASTM STP 717 (Casper and Pinchback, 1980) includes numerous papers on corrosion and scaling. Further examples are provided by Culivicchi et al. (1985), Corsi (1986), Lichti et al. (1995), Celant and Smith (1995), Bacon et al. (1995), and Bracaloni et al. (1995). Jung (1997) identified corrosion resistant liners for pipelines and casing, specifically those which can be applied in-situ as a materials need. Dr. Norio Sanada of the Tohuko National Industrial Research Institute in Japan has conducted a literature survey for the Materials Subtask of the IEA Research Collaboration Program and kindly supplied a list of journal and conference publications.

The April 1997 GEA Workshop produced a list of recommendations for R&D. Those specifically related to materials included:

- Continue to develop and demonstrate coatings, especially those that can be applied in the field
- Develop materials for use in turbine manufacture that allow closer tolerances in rotating equipment, leading to improvement in efficiency
- Continue to work on monitoring and mitigating the effects of corrosion damage
- Develop methods of integral welding of turbine blades to disks
- Develop designs for condensers made of cheaper materials, perhaps with coatings, that would allow local manufacture.
- Consider the use of composites and titanium for turbine blades

RESULTS OF SURVEY

Question 1. What is your role/interest in O&M of geothermal power plants?

The majority of the respondents were responsible for engineering, maintenance, operation and management of power plants. The remainder were consultants to the geothermal industry.

Question 2. What percentage of total power plant operating costs would you estimate are a direct result of materials-related problems?

The responses are shown graphically in Figure 1. The most frequent response (i.e., the mode) was 10-20%. One respondent noted that this is highly dependent on actual field location and could be >30% in some fields. The one response for the 80-90% category was associated with fluid collection and disposal systems. One respondent noted that this question was not specific enough.

Question 3. Based on your experience, what is the frequency of the following types of materials-related problems? (Give examples of component affected if possible).

In this question participants were asked to rate the frequency of different forms of failure or other problems. Both broad (e.g., all forms of corrosion) and specific (e.g., stress corrosion cracking) problems were included. The results are given in Figure 2. The most frequent problems were corrosion (all forms), scaling, microbiologically influenced corrosion, erosion corrosion, and stress corrosion cracking. The latter three also received responses in the "Rarely" category, hence there is some divergence. One respondent commented that scaling is the number one cause of shutdown and that microbiologically influenced corrosion is the major reason for using stainless steel and fibre reinforced plastic circulating pipes instead of carbon steel.

Table 1 lists the examples of components affected by the specific problems that the respondents gave.

Table 1. Examples of components involved

Problem	Components
Corrosion (all forms)	Turbine blades/nozzles/rotor, pipelines, vessels, expansion bellows, NCG pipelines, wells, fluid collection and disposal systems, all components, valves, condensers, electrical systems
Scaling	Turbine blades, first stage nozzle box, wells, pipelines, reinjection pumps, separators, condenser tubes, valves, let down valves at well heads, pumps
Stress corrosion cracking	Turbine blades/rotor, stainless steel vessels, piping, pipe elbows, heat exchangers, 316/304 stainless steel rupture disks, security valves, wherever 300 series stainless steel used, duplex stainless steel, some higher Ni alloys, condensers, valve shafts
Erosion corrosion	Turbine blades/rotor, LP blades last stage, steam separators, production piping, reinjection piping, process piping, gland seal system, valve seats
Microbiologically influenced corrosion	Cooling towers (including concrete above vapour space), heat exchangers, pipelines, tube and shell main condenser, condenser tubes, valves
Fatigue	Turbine blades/rotor, pipelines, condensers, heat exchangers, rotating equipment
Corrosion fatigue	Turbine blades/rotor, pipelines, condensers, condenser tubes, rotating equipment
Solid particle erosion	First stage nozzle box, turbine blades/nozzles/seals, well components, pipelines
Wear (all forms)	Turbine blades/rotor, valve stem, steam seals, steam scrubbers, valves, steam equipment exhaust, compressors
Coating failure	Turbine casing, pipelines, well/line valves, silencers, epoxy coating on mild steel condenser, cooling tower fan gear boxes, miscellaneous plant structural steel, Teflon linings, circulating water pipes, Sulfatreat pressure vessels
Creep	Teflon linings
Yielding	Wells
Fracture	Well casing, turbine blades, stainless steel vessels, pipelines, welds
Combination	Turbine blades

Question 4. Indicate the extent of use of the following materials and strategies to mitigate materials-related problems.

This question was divided into four parts:

a. Materials
b. Treatments
c. Inspection/Maintenance
d. Basis for materials selection

Figures 3 to 6 show the results for this question. For part a), the most frequent response was corrosion resistant ferrous alloys, followed by coatings and linings. The most commonly used treatment (part b) was biocides. The most common form of inspection (part c) was visual followed by non-destructive testing. The overall responses for preventive and corrective maintenance were similar. With regard to materials selection (part d), 100% of respondents said that prior experience was often the basis. In-house evaluation and combination of different factors were the other most frequent responses. Life cycle cost analysis, minimum cost and minimum failure tended to be used only sometimes or rarely.

Question 5. Based on your experience, indicate the extent of use of different coatings/linings and application methods in geothermal power plants.

This question was designed to provide information on what types of coatings and application methods are most commonly used. The percentages of "Don't know" and "No response" were relatively high for this question. The responses are given in Figure 7. Of the four generic coating materials, metal appeared most often. Brush/roller or spray painting were the most common application methods. Chemical vapour deposition/physical vapour deposition (CVD/PVD) did not receive many responses.

Question 6. Typically, what are the greatest barriers to using new or alternative materials and technologies to mitigate materials-related problems?

Figure 8 presents the results for this question. Unfavourable life cycle cost analysis was often rated as a barrier to using new or alternative materials and technologies. However, there was also a sizeable percentage of responses in the "Rarely" category. In Question 4d it appeared that life cycle cost analysis is not used extensively. Insufficient performance data and high initial cost also appear to be barriers. For the "High risk" option the percentage responses for the "Often" and "Rarely" categories were equal. Similar findings were obtained for the "Requires special expertise/equipment" option. This indicates high variability in viewpoints.

Question 7. What sources of information do you use to keep up to date with materials-related research and development?

The purpose of this question was to identify where the geothermal industry seeks information so that these sources can be targeted in the interests of technology transfer. Figure 9 shows that industry publications, published conference proceedings and technical journals received the most frequent responses. Research reports by national laboratories and universities were not frequently used. The responses for electronic databases and the World Wide Web were varied. Some respondents noted that they are not yet connected to the Web or do not have access to these two sources. One respondent noted use of the GRC Online Library.

Question 8. How would you rate the importance of the following in reducing O&M materials-related costs?

This question posed several options that could assist in reduction of O&M costs associated with materials problems. The results are presented in Figure 10. Optimization of currently available materials and technologies, life extension of existing equipment and service life prediction were rated of high importance. Education and training were also important. Development of new materials and technologies and better methods for in-situ coating applications were of lower importance than other options. It is significant that the respondents viewed optimization of currently available technologies and materials of greater importance than new materials.

Question 9. List O&M materials-related research needs in order of priority that you believe would have the greatest impact on improving materials performance, enhancing efficiency and reducing O&M costs.

The suggestions received are listed below in no particular order. A new style of bullet indicates the start of the list for a new respondent.

- ● Better understanding and prediction of material behaviour through modelling
- ● Better inspection and maintenance scheduling through performance prediction and correlation with condition assessment and nondestructive tests
- ● Emphasis on effectively utilizing existing materials and protective measures rather than developing new materials
- ● More consideration to design aspects
- ■ Applications and introduction of modern coatings technology to geothermal industry
- ■ Organize a special seminar on O&M cost reduction potentials via materials advances already known
- ■ R&D on instrumentation for corrosion monitoring and inspections
- ■ Provide materials R&D information and advanced work on dual/clad components
- ■ R&D for introduction of special corrosion resistant alloys in critical corrosion areas/components
- ■ Analyses of typical two-phase flow situations that cause enhanced corrosion in critical flow areas
- ■ Conduct R&D on improved chemicals for injection for corrosion inhibitions specific to geothermal application
- ▸ Dual function scale/corrosion inhibitors
- ▸ Improved bonding of coatings to carbon steels
- ▸ Improved biocides, more environmentally safe biocides
- ▸ Non-fouling packings in condensers and cooling towers
- ▸ Cheaper H_2S abatement chemicals/more effective systems
- ▸ Corrosion/erosion resistant turbine nozzles and blades
- ● Service life prediction of materials and coatings in geothermal environments
- ● Non-destructive testing for damage

- High performance corrosion and wear resistant coatings that can be applied in-situ
- Better biocides for cooling towers
- Protection of concrete from microbiological attack in cooling towers
- Coatings resistant to biocorrosion
- Refurbishment of worn and corroded equipment
- Engineering analysis and modeling of equipment/materials, including coated materials, to calculate effects of thermal and mechanical stresses
- Prediction of remaining life from non-destructive evaluation, especially turbine blades and rotors
- Lower cost materials for well casing in corrosive fields
- Prevention of turbine blade and rotor failures
- Lower cost methods for protecting carbon steel pipelines in geothermal production gathering systems
- Prevention of calcium carbonate and silica scaling in production and injection systems
- Better methods of turbine washing while online
- Improved non-destructive testing methods
- Improved methods for descaling pipelines and wellbores
- Know materials of construction
- Know type of geothermal fluids
- Know the chemistry of steam supply
- Establish factors promoting material failures
- Material selection suitable to geothermal environment
- Research to focus and address impact of corrosive compounds in geothermal fluids (i.e., H_2S, Cl^-, NH_3, CO_2, SiO_2)
- Corrosion resistant coatings to enable use of lower cost materials on NCG and condensate pipelines
- Reduced capital cost of plant in order to make geothermal more cost competitive
- Research into effects of geothermal service conditions on polymeric materials
- Prevention of corrosion problems with equipment parts exposed to geothermal gases in wet and dry cycle conditions. This is related with the barometric condenser legs discharging in the hot well. This leg is exposed to the H_2S associated with wet and dry cycles, accelerating corrosion and loss of vacuum in the main condenser.
- Prevention of corrosion problems in concrete structures. We have experience with degradation of the concrete and attack of steel exposed to H_2S.
- Prevention of corrosion in the fans of cooling towers when the NCG are dispersed in the top of the tower.
- Prevention/removal of mineral deposits on turbine blades
- In-situ placement of repair liners/coatings in pipelines and well casing
- Scale inhibitors
- Control of microbiological attack
- Good, stable coatings on carbon steel in the condensing flow systems of the power plant to reduce capital cost
- Good permanent coatings in carbon steel well casings

- Coatings to prevent scaling in separators
- Corrosion resistant ferrous alloys
- Cladding
- Non-ferrous alloys
- Polymers
- Coatings and linings
- Ceramics
- The materials, at least in terms of metals and alloys, are available. It is a matter of proper application, knowledge and experience.
- Lower cost, more corrosion resistant pipeline materials than carbon steel
- Turbine material problems may best be handled by keeping steam clean. Use existing technology rather than developing new turbine materials due to complexity and issues unrelated to geothermal corrosion such as operating stresses, vibration, cost etc.
- Cathodic protection
- Corrosion resistant alloys
- Polymers for repair and protection
- Corrosion inhibitors
- Reducing capital cost: -less expensive cooling water pipes
- Reducing maintenance cost: -improved turbine blade materials/costs
  -turbine coatings
- Well completions for acid-sulfate wells
- Effect of NCG content on plant equipment life (0.5-5% NCG)

Question 10. Do you have any other comments?

The various comments received are quoted below.

- "Education and awareness must be improved".
- "I'd like to see better use of computer modeling of materials and components to analyze stresses and response, predict performance and identify the controlling parameters".
- "We need expertise on corrosion engineering, process chemistry, process design engineering and quality assurance engineering".
- "To become cost-effective in today's competitive power generation environment, the capital cost of geothermal plants must be reduced. The successful use of polymeric materials and new coatings to enable cheaper materials to be used in the construction could be one way of achieving such cost reductions".
- "It does not matter what you do as long as it is cheap for industry to implement and will make them money. Cost-effective results!"
- "....a series of on-site seminars or workshop for the operational and maintenance personnel would be most valuable. They would stress the items noted from this survey, and in addition would introduce the modern trends in corrosion and materials related R&D being conducted currently. ....it would be of great benefit to set up some sort of 'advisory panel' from among the geothermal O&M supervisory personnel".

- "The ability to develop good, stable, permanent coatings to prevent corrosion, erosion and scaling will have great value in reducing the basic cost of geothermal power. These coatings will reduce capital cost as well as O&M costs".
- "....very little usage of organic corrosion inhibitors; too expensive".
- "The major problems I have encountered have been due to corrosion effects associated with failure to use existing technology to assure optimum purity of steam to the power plant components during plant operation and proper care during shutdown. In some cases with steam resources, the situation is complicated by changes in steam chemistry as the field ages. However, since geothermal turbines have been in operation for over 50 years, considerable technology has been developed and reported to handle most of these problems as long as personnel associated with the design and operation of the geothermal power plant people are aware of them".
- "If the findings of R&D are to be implemented in geothermal plants they need to be presented in a language that plant engineers can understand".

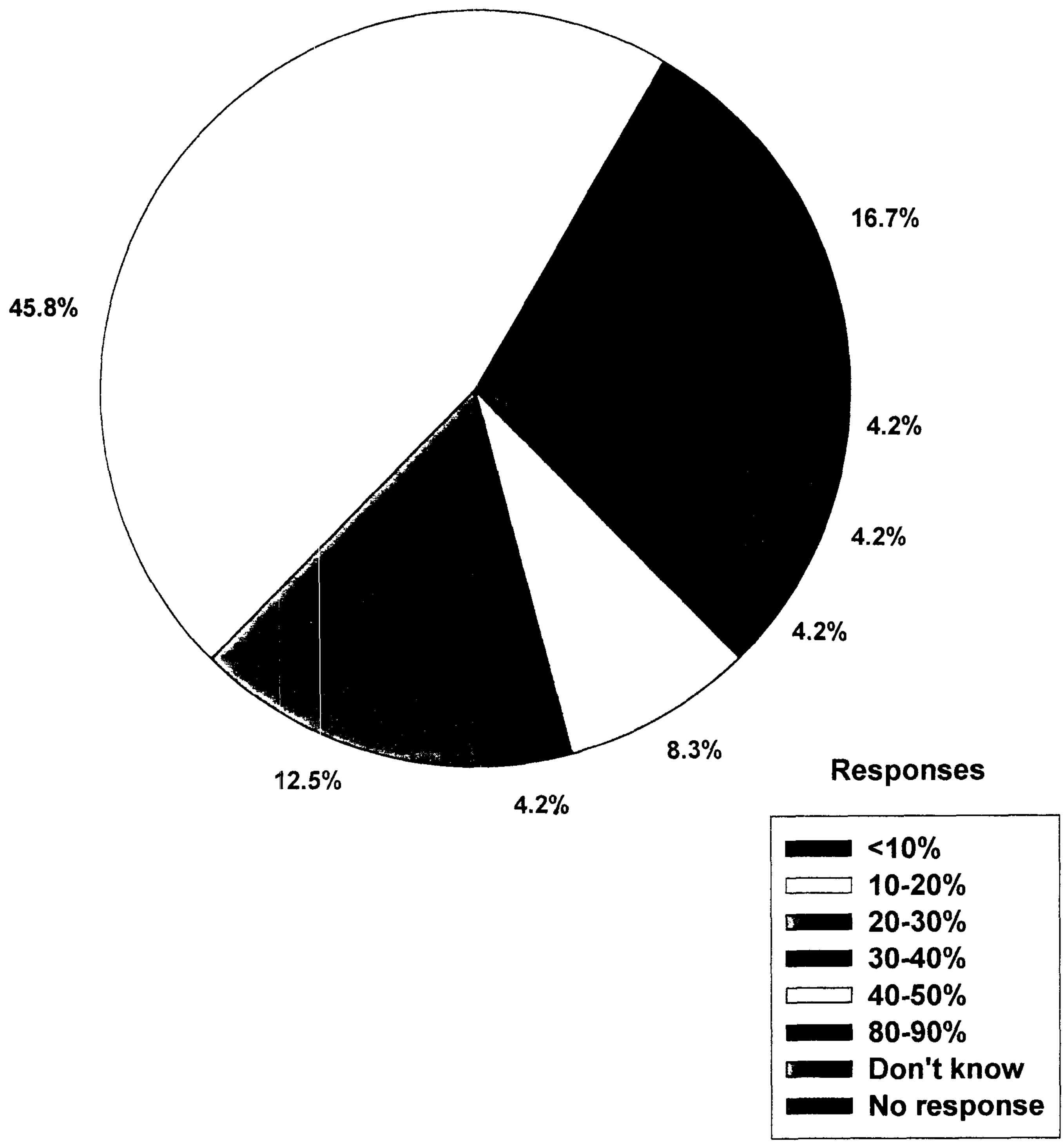

Figure 1. Percentage of total power plant operating costs estimated as a direct result of materials-related problems. (Question 2).

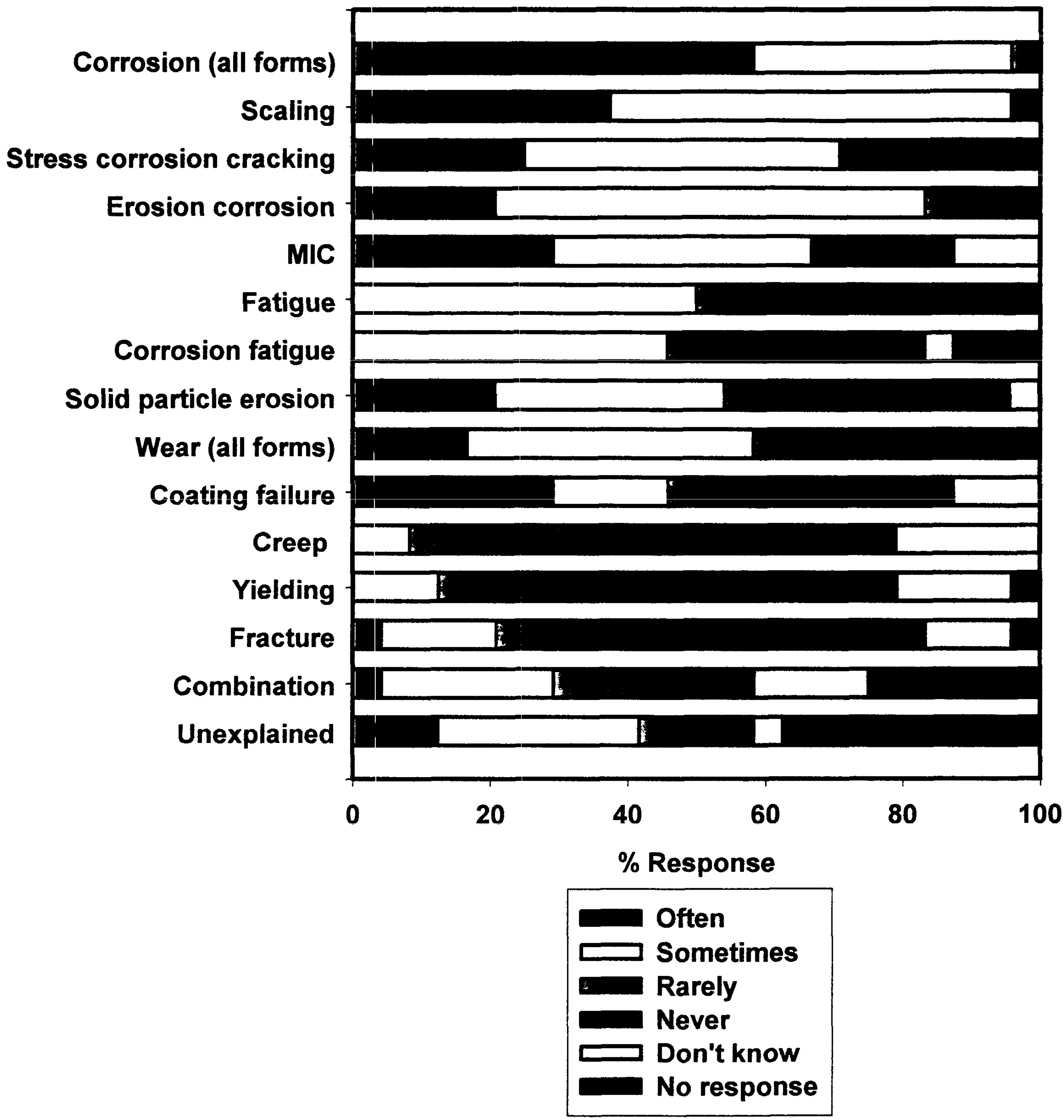

Figure 2. Frequency of different types of materials-related problems. (Question 3).

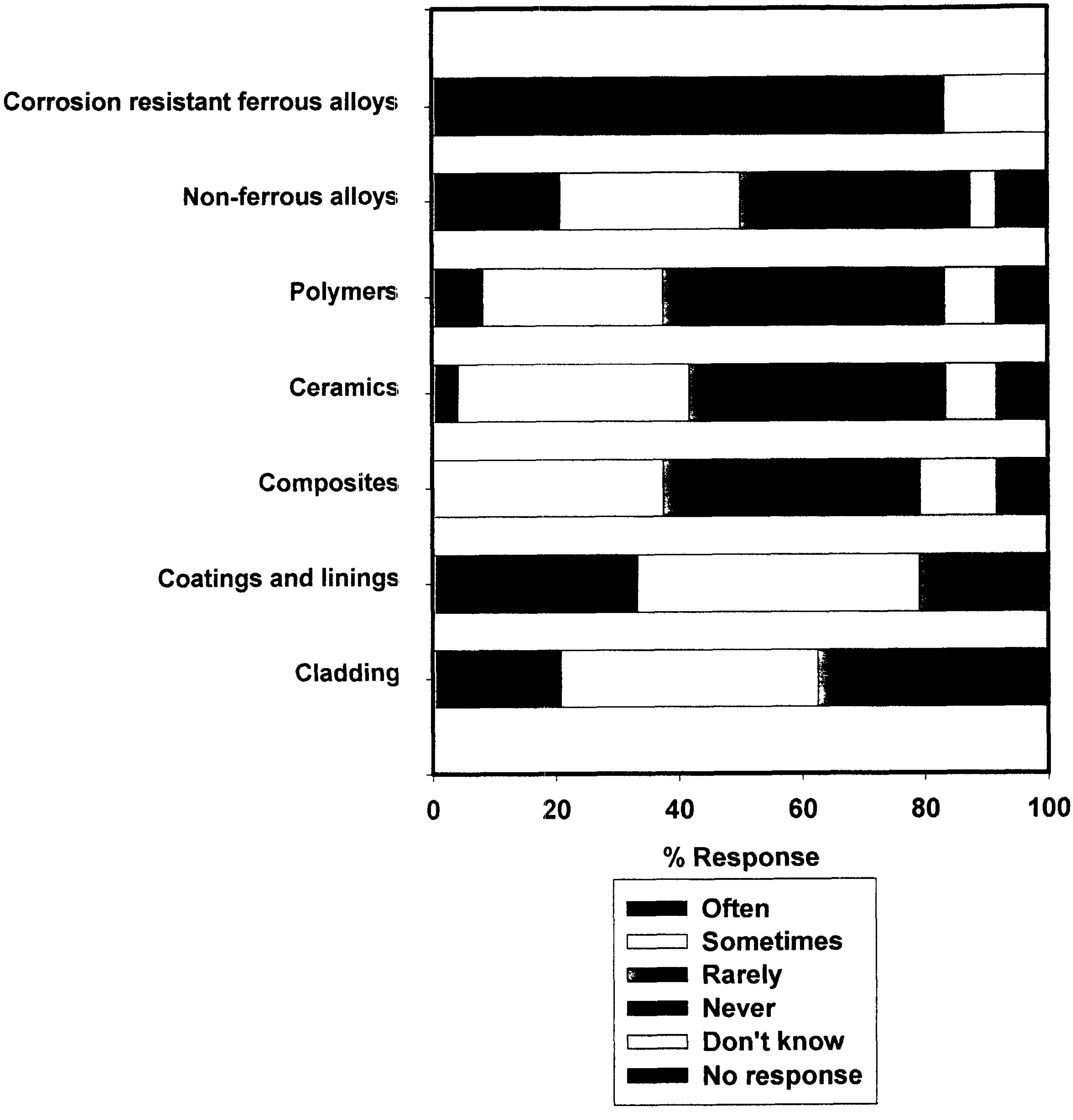

Figure 3. Frequency of use of different materials to address problems. (Question 4a).

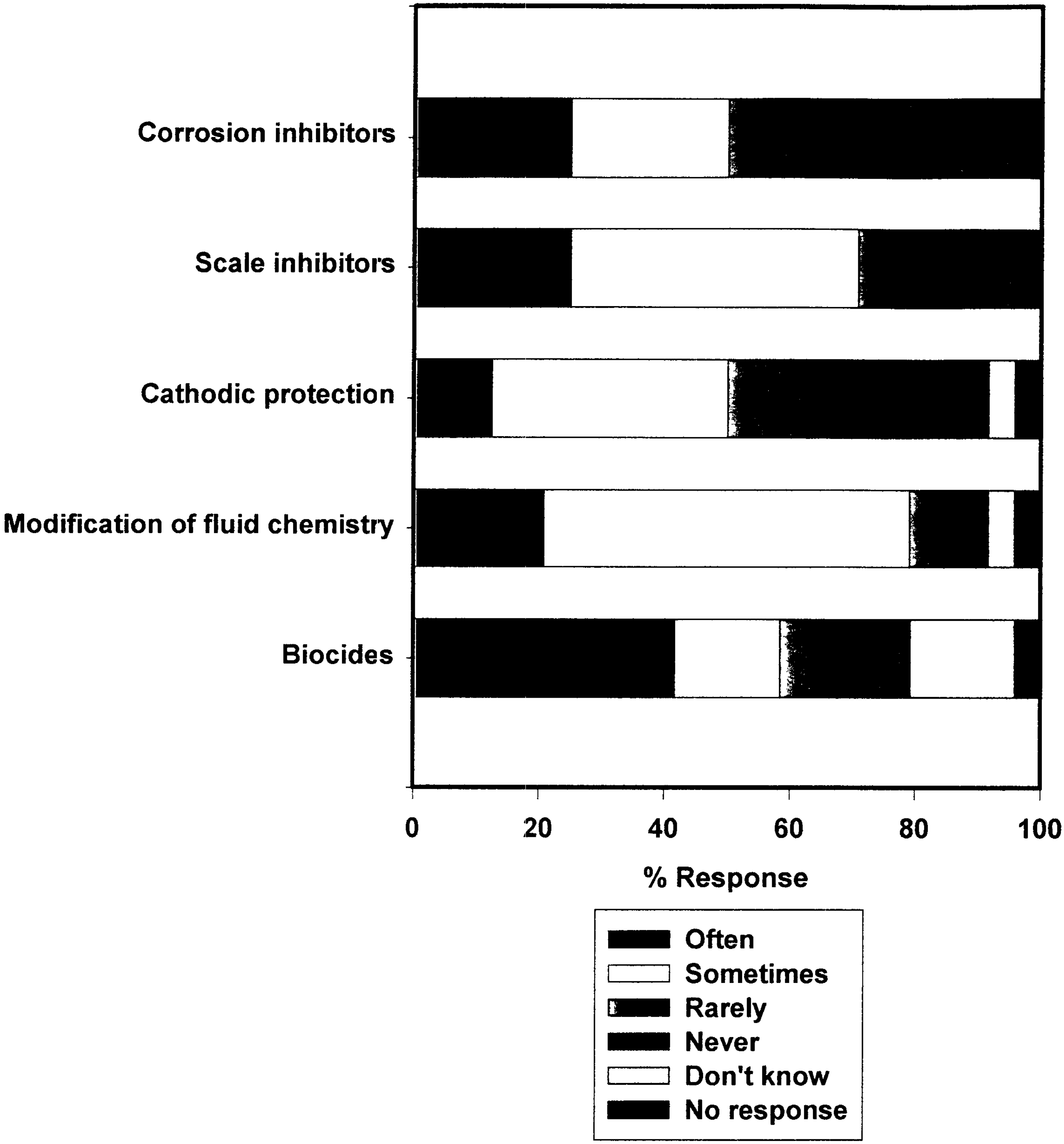

Figure 4. Frequency of treatments to address materials problems. (Question 4b).

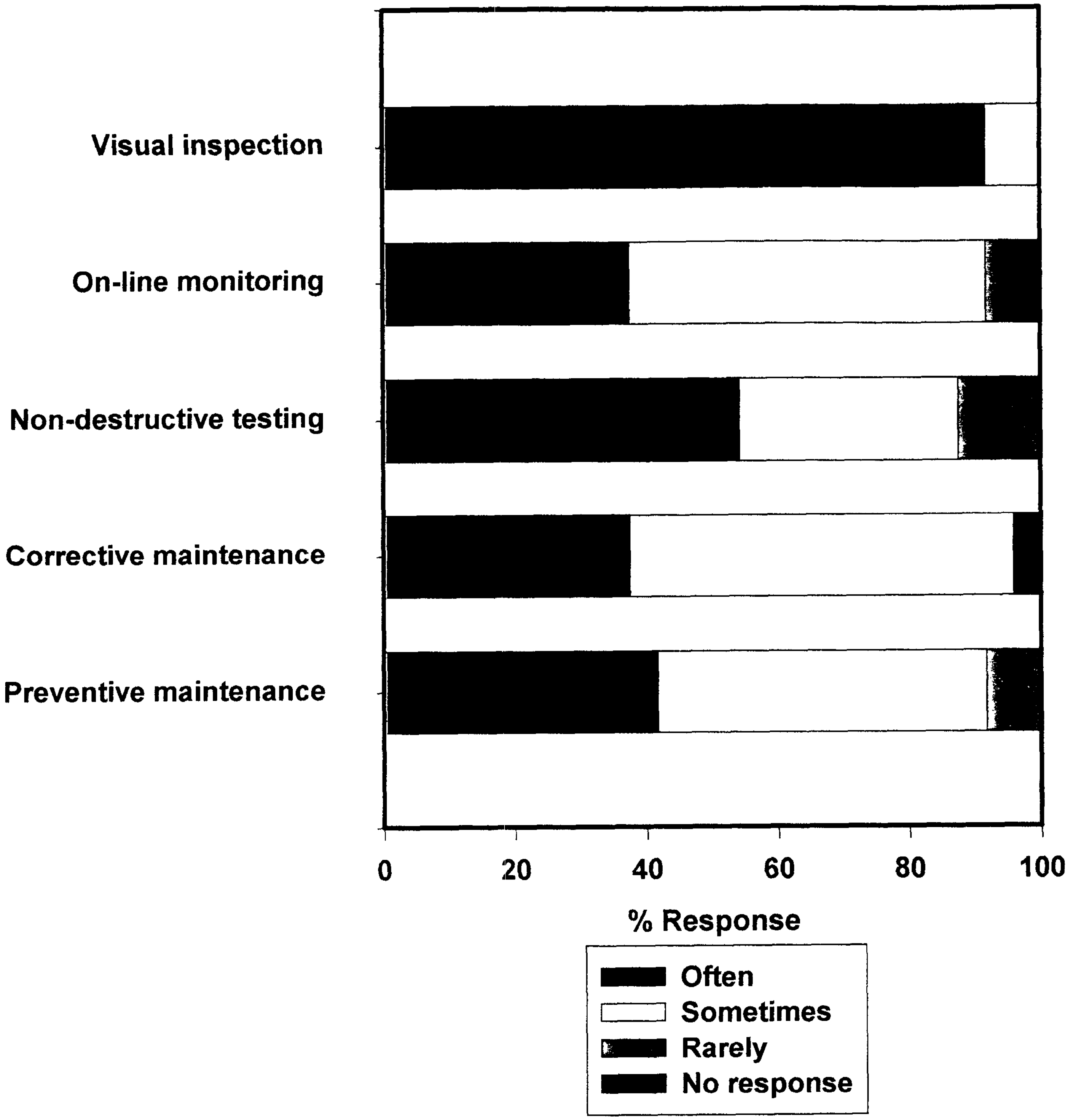

Figure 5. Frequency of use of different inspection and maintenance strategies. (Question 4c).

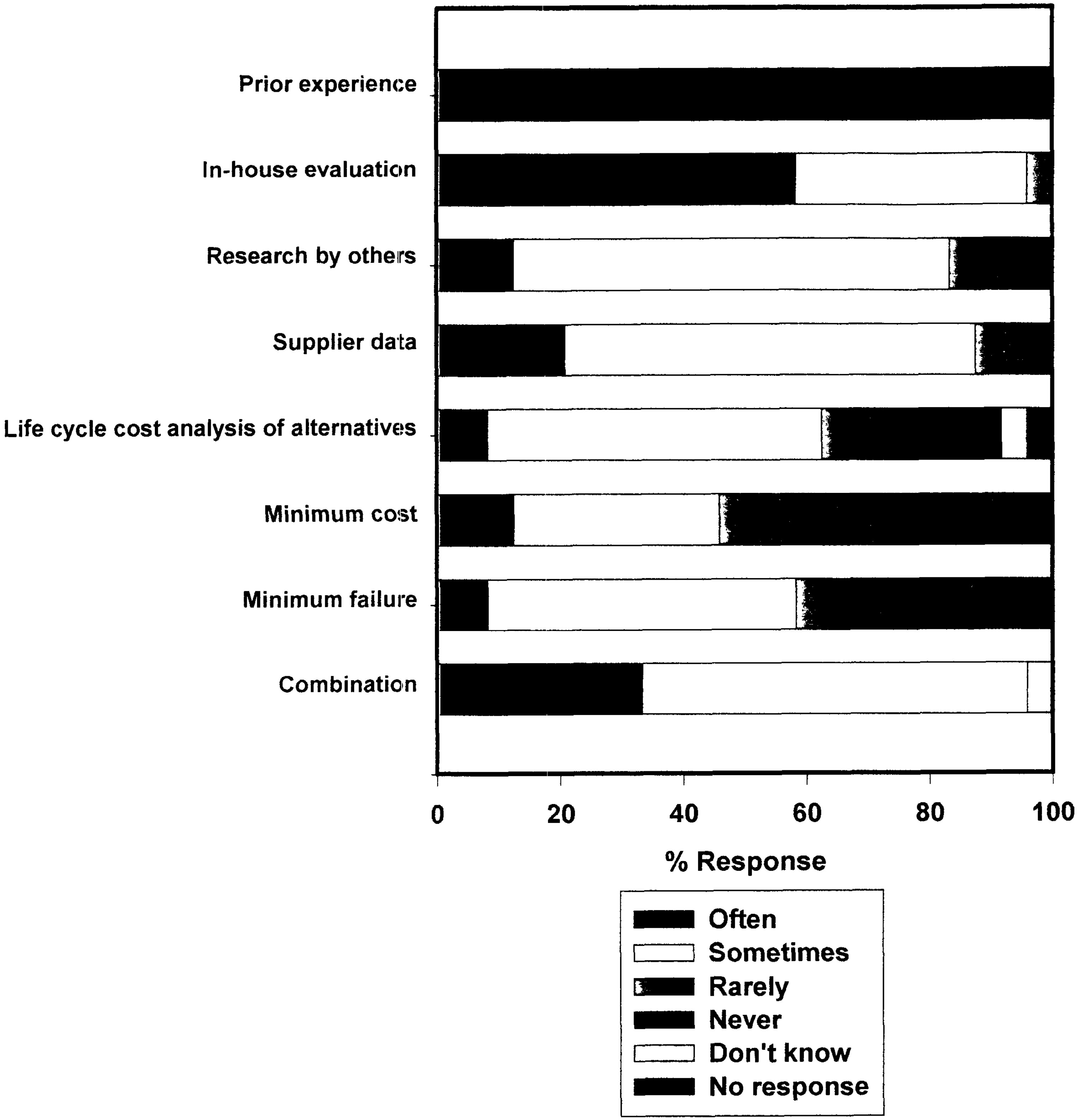

Figure 6. Frequency of basis for materials selection. (Question 4d).

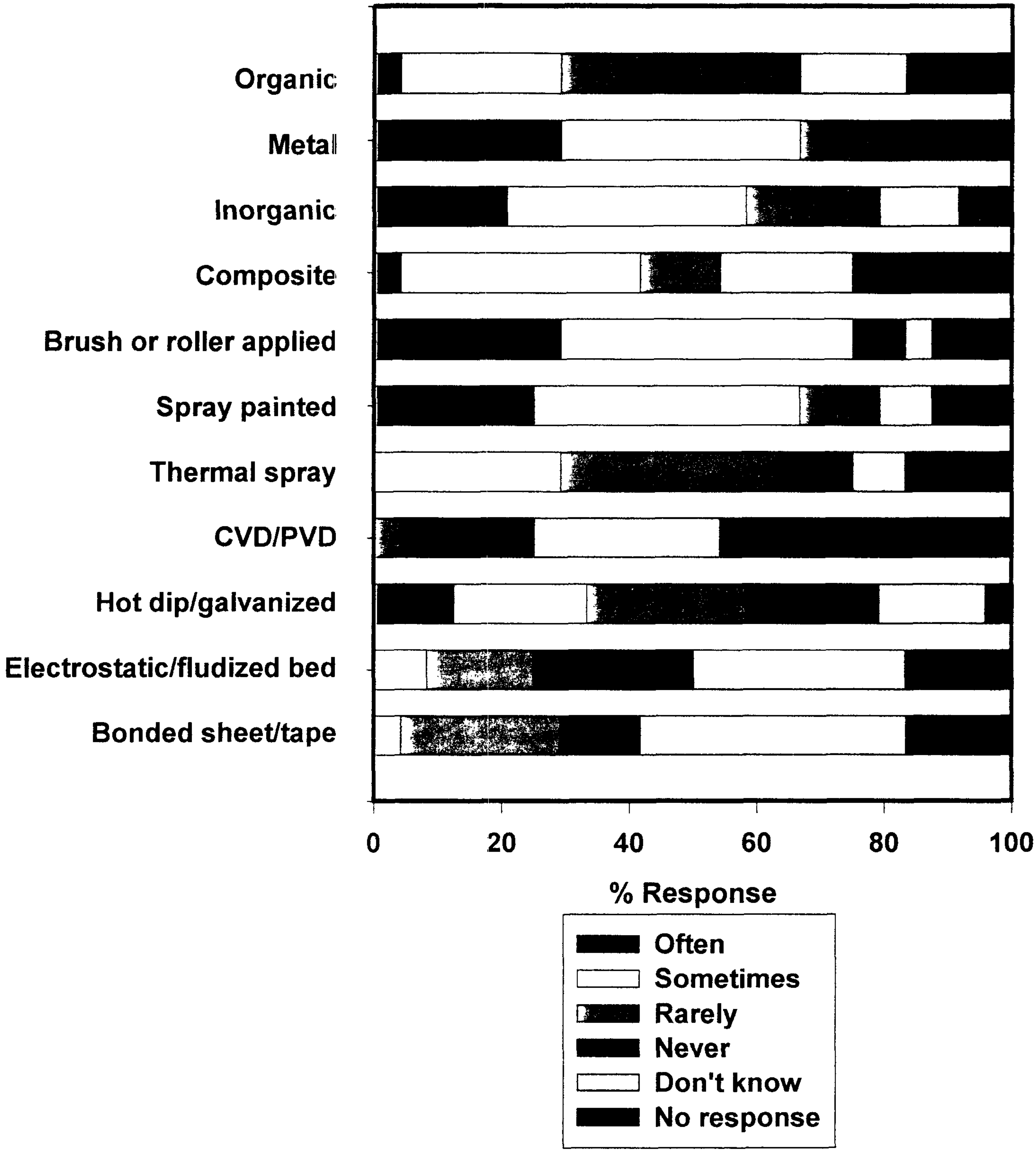

Figure 7. Extent of use of different coatings/linings and application methods. (Question 5).

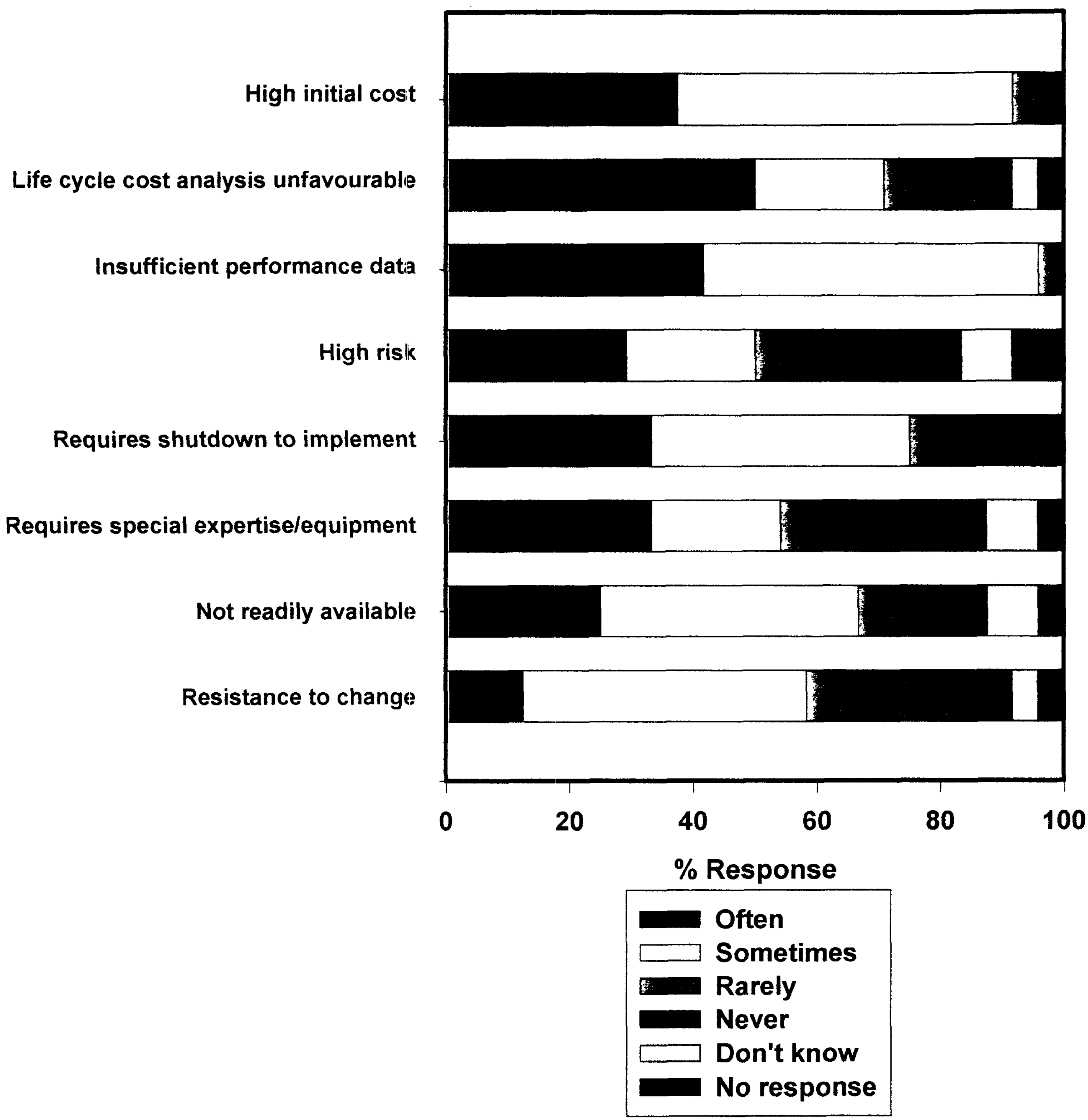

Figure 8. Greatest barriers to using new or alternative materials and technologies to mitigate materials-related problems. (Question 6).

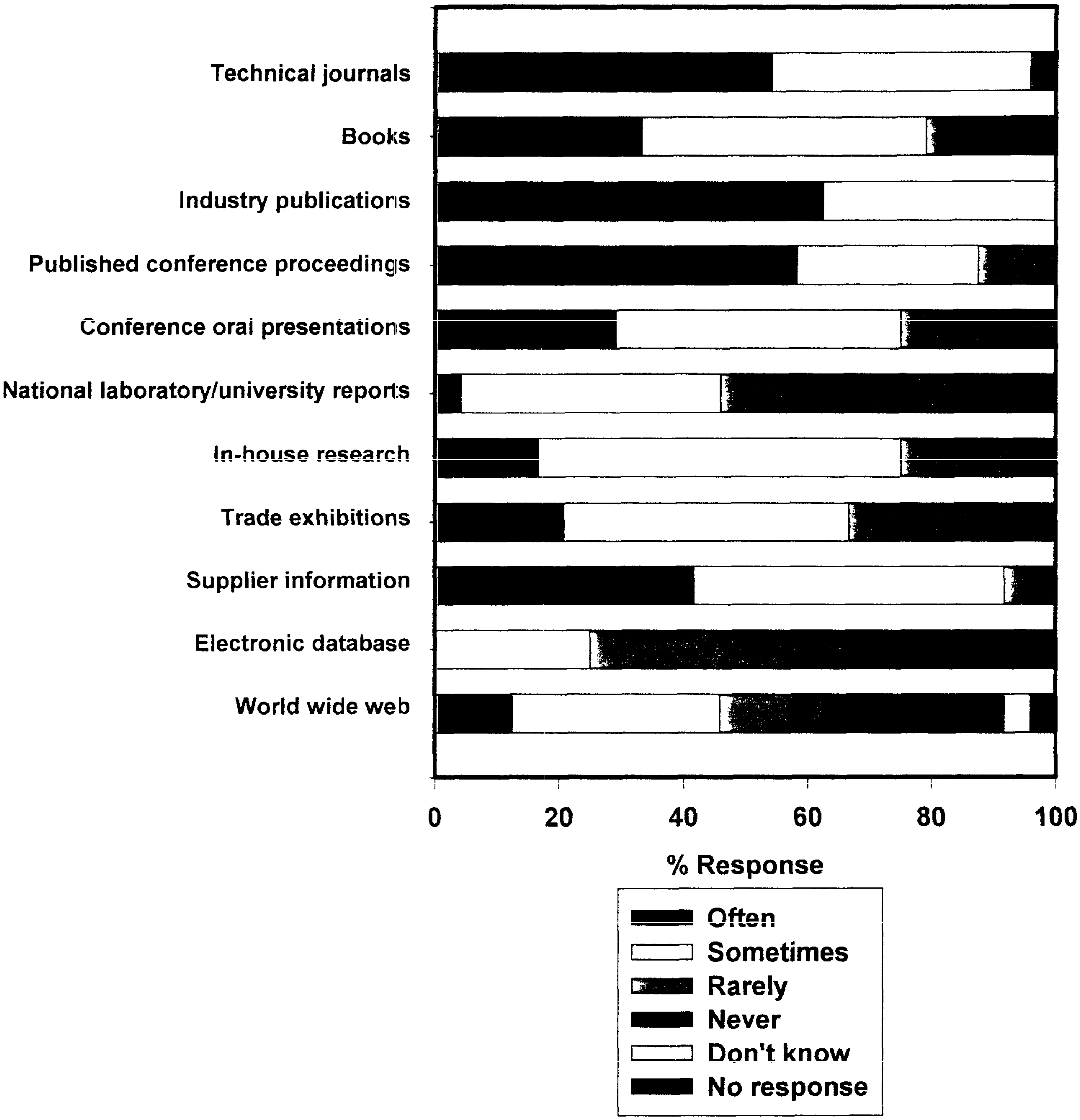

Figure 9. Sources of information used to keep up to date with materials-related research and development. (Question 8).

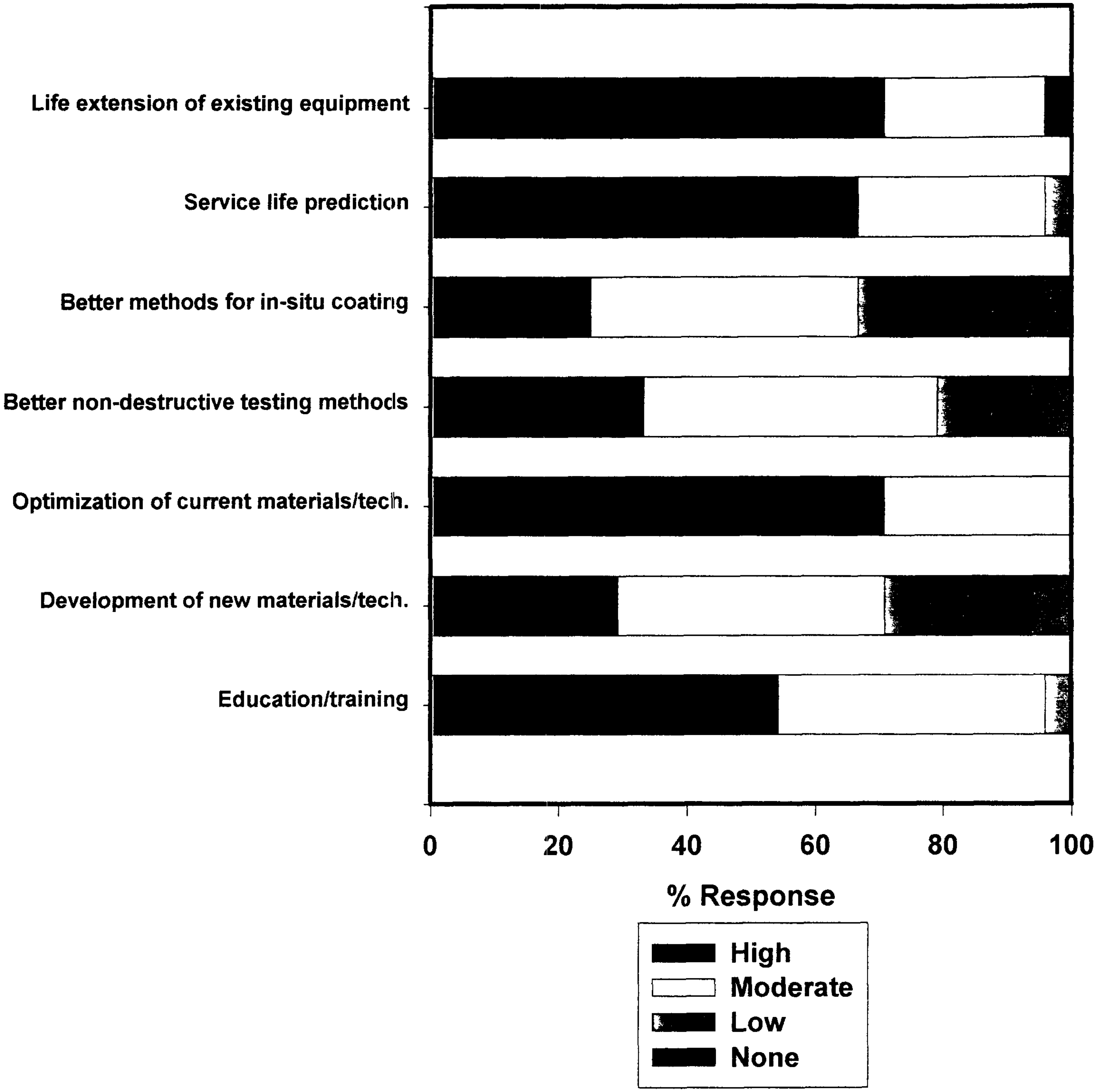

Figure 10. Importance of example areas in reducing O&M-related materials costs. (Question 8).

ANALYSIS OF RESULTS

The survey provided valuable insight on the major areas of concern and how these might be addressed. Given that the sample was relatively small, the survey was qualitative and that opinions are diverse, several inferences can be made. These are based on the responses received.

Corrosion (including microbiologically influenced corrosion, stress corrosion cracking and erosion corrosion) and scaling are still the leading problems that must be tackled to reduce O&M materials-related costs. The components typically affected are turbine blades, nozzles and rotors, pipelines, cooling towers, condensers, valves, well casings and heat exchangers. Microbiological attack of concrete and metal in cooling towers was listed by several respondents. Hence, it is not only geothermal fluids that are causing corrosion in plants.

Corrosion resistant ferrous alloys appear to be used frequently to combat problems, where as non-metallic materials (polymers, ceramics and composites) are less widely used. Non-metallics have potential for use in aggressive environments provided that the mechanical properties, practicality and economics are appropriate, in addition to chemical resistance. Coatings and cladding see some use and could possible be extended. The use of coated low cost construction materials (e.g., carbon steel), use of modern coatings and technology, engineering analysis of coated materials, and in-situ application and repair of coatings were listed as research needs by several respondents. In particular, coatings/liners for pipelines and well casing appear to have strong interest.

The responses for treatments used were diverse. Of these, biocides were most frequent. Some of the suggestions in Question 9 for research needs referred to improved biocides, environmental safe biocides and protection of concrete in cooling towers. Modification of fluid chemistry (e.g., pH control) received a high response for the "Sometimes" category. The responses for "Rarely" outweighed those for "Often" for the use of corrosion inhibitors. Improvements in inhibitor performance and reduction in cost could possibly increase the usage and benefits of inhibitors. Corrosion and scale inhibitors were mentioned several times as research needs, including suggestions for dual function inhibitors and corrosion inhibitors specifically for geothermal applications.

Visual inspection is apparently used often as well as non-destructive testing. Several respondents noted the need for improved non-destructive testing and predicting performance/remaining life from such tests. Preventive maintenance to avoid failures or deterioration received a similar distribution of responses as corrective maintenance.

The unanimous response for often using prior experience as the basis for materials selection indicates a strong reliance on past performance data. In-house evaluation is rated higher than research by others. This, together with using prior experience, implies that first hand knowledge of a material's performance is very important in materials selection for the respondents. Different fluid chemistry and plant operating conditions may contribute to this strategy since what is reported to work well in one case may not be uniformly applicable. Also, the required data in geothermal environments to justify selecting a particular material or to conduct life cycle cost analysis of alternative materials may be unavailable or limited.

The scatter in responses on coatings and linings prohibits identification of strong preferences. Metal and inorganic coatings appear favoured over organic and composite. Coatings were listed as research needs, particularly for corrosion protection of carbon steel. Suitable coatings for wear and biocorrosion resistance were also mentioned. The use of coatings to reduce capital costs in addition to O&M costs is also important.

Responses were also varied on the issue of barriers to using new or alternative materials and technologies. High initial costs, unfavourable life cycle cost analysis and insufficient performance data need to be addressed in R&D on materials for geothermal applications to remove these barriers. Consideration should also be given to the practical aspects of implementing alternatives.

The respondents preferred technical journals, industry publications and published conference proceedings as sources of information on materials R&D. Therefore, greater effort should be made to publishing the findings of R&D in these forms. The low apparent usage of university or national laboratory research reports is possibly due to insufficient distribution to interested parties. Also, one respondent commented that the findings of R&D need to be in a language that plant engineers can understand and this should be taken more into account when writing reports. The usage of electronic databases and the World Wide Web may increase in the future as more information is available from these sources and access increases. Brookhaven is in the process of making reports available in PDF format. Ensuring that research publications are listed on the GRC On-line Library would also be useful.

Life extension of existing equipment, service life prediction, optimization of currently available materials and technology, and education were of relative importance to the respondents in reducing O&M costs. The research needs and additional comments in Questions 9 and 10 also identified these areas. The need for predicting performance and relating this to non-destructive tests was noted as was refurbishment of worn and corroded equipment. Respondents commented that existing materials should be used more effectively through appropriate application, design, knowledge and experience. One respondent felt that problems encountered with turbines could be handled by keeping the steam clean rather than developing new materials. Therefore, it is clear that effort should not be solely directed towards new materials. A balance between optimizing currently available materials and technologies and taking advantage of new advances in materials and damage mitigation strategies must be maintained.

Question 8 saw a varied response for better non-destructive testing methods. However, several respondents listed this in research needs under Question 9. Education of plant personnel in materials advances, coating technologies and control of corrosion, erosion and scale is a logical and effective way of increasing awareness of how problems can be addressed. The suggestion of seminars or workshops should be pursued.

The research needs and comments listed by the respondents were numerous and diverse. On some issues there is a consensus, whereas divergence occurs with others. The most significant/frequent needs and comments are summarized below in no particular order:

- Service life prediction by modelling and correlation with condition assessment and non-destructive tests
- Effective utilization of existing materials and technologies through appropriate selection, design, application, knowledge and experience
- Coatings for corrosion, wear, scale and biocorrosion control. Coatings for carbon steel, well casings and pipelines and methods for in-situ placement
- Improved instrumentation/non-destructive testing for monitoring damage
- Performance of corrosion resistant alloys, clad materials, polymers
- Improved biocides
- Protection of concrete in cooling towers
- Improved scale and corrosion inhibitors
- Prevention of corrosion, erosion and scaling in turbines
- Prevention of corrosion in condensers
- Protection from corrosive effects of NCG
- Reduction of capital costs
- Keeping steam clean to prevent problems in turbines
- Seminars and educational activities for plant personnel

RECOMMENDATIONS

Corrosion, including microbiologically influenced corrosion, and scaling remain the major sources of materials-related O&M costs and should continue to be addressed in R&D. This R&D should not be solely directed towards new materials. Optimization of existing materials and technologies through better design and enhanced understanding of response to the conjoint action of environment and operational stresses is of great importance. Integration of modelling materials performance and service life with pertinent experimental and operational data would expedite this objective and be an efficient use of time and resources.

Research should be directed at detecting, mitigating and preventing problems in components such as pipelines, well casings, turbines, heat exchangers, valves, condensers and cooling towers. Improvements in scale and corrosion inhibitors and biocides are also required. Life extension is likely to become an increasingly important issue as plants age.

Since the survey found that materials selection is largely based on previous performance data it is important for the geothermal industry that this data be readily available and that collection of long term performance data for new and alternative materials be included in R&D on such materials. Joint commitment by plant operators and researchers to monitor new and alternative materials exposed to operating conditions over extended periods and thereby generate useful performance data for future use and life cycle cost analysis would justify selection of particular materials. This type of data would also be useful when expanding existing or constructing new plants.

Dissemination of research findings needs to be improved. Research reports appear to be a relatively ineffective form of technology transfer with the current distribution system. Greater emphasis should be placed on publication in journals and conference proceedings, in addition to improving the ease of understanding by end users. Electronic sources of information may find greater use in the future. Continued education of geothermal plant O&M personnel in the optimal use of new and existing materials and technologies for mitigating corrosion and scaling is key to implementation of research.

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APPENDIX A: QUESTIONNAIRE

1. What is your role/interest in O&M of geothermal power plants?

2. What percentage of total power plant operating costs would you estimate are a direct result of materials-related problems?

☐ <10% ☐ 10-20% ☐20-30% ☐ 30-40% ☐ 40-50% ☐ 50-60%

☐ 60- 70% ☐ 70-80% ☐ 80-90% ☐ >90% ☐ Don't know/Not applicable

3. Based on your experience, what is the frequency of the following types of materials-related problems? (Give examples of component affected if possible).

	Often	Sometimes	Rarely	Never	Don't Know	Examples of Components
Corrosion (all forms)						
Scaling						
Stress corrosion cracking						
Erosion corrosion						
Microbiologically influenced corrosion						
Fatigue						
Corrosion fatigue						
Solid particle erosion						
Wear (all forms)						
Coating failure						
Creep						
Yielding						
Fracture						
Combination						
Unexplained						
Other (describe)						

4. Indicate the extent of use of the following materials and strategies to mitigate materials-related problems:

a: Materials

	Often	Sometimes	Rarely	Never	Don't Know
Corrosion resistant ferrous alloys (e.g., stainless steels)					
Non-ferrous alloys (e.g., Ti- and Ni-base alloys)					
Polymers					
Ceramics					
Composites					
Coatings and linings					
Cladding					
Other (describe)					

b: Treatments

	Often	Sometimes	Rarely	Never	Don't Know
Corrosion inhibitors					
Scale inhibitors					
Cathodic protection					
Modification of fluid chemistry					
Biocides					
Other (describe)					

c: Inspection/Maintenance

	Often	Sometimes	Rarely	Never	Don't Know
Visual inspection					
On-line monitoring					
Non-destructive testing					
Corrective maintenance					
Preventive maintenance					

d: Basis for materials selection

	Often	Sometimes	Rarely	Never	Don't Know
Prior experience					
In-house evaluation					
Research by others					
Supplier data					
Life cycle cost analysis of alternative materials					
Minimum cost (use of least expensive material followed by periodic replacement)					
Minimum failure (use of best material regardless of cost)					
Combination of one or more of above					
Other (describe)					

5. Based on your experience, indicate the extent of use of different coatings/linings and application methods in geothermal power plants:

	Often	Sometimes	Rarely	Never	Don't Know
Organic					
Metal					
Inorganic					
Composite					
Brush or roller applied					
Spray painted					
Thermal spray					
CVD/PVD					
Hot dip or electroplated					
Electrostatic or fluidized bed					
Bonded sheet/tape					
Other (describe)					

6. Typically, what are the greatest barriers to using new or alternative materials and technologies to mitigate materials-related problems?

	Often	Sometimes	Rarely	Never	Don't Know
High initial cost					
Life cycle cost analysis unfavourable					
Insufficient performance data					
High risk					
Requires shutdown to implement					
Requires special expertise or equipment					
Not readily available					
Resistance to change					
Other (describe)					

7. What sources of information do you use to keep up to date with materials-related research and development?

	Often	Sometimes	Rarely	Never	Don't Know
Technical journals					
Books					
Industry publications					
Published conference proceedings					
Conference/workshop oral presentations					
National laboratory/university research reports					
In-house research					
Trade exhibitions					
Supplier information					
Electronic database (e.g., Compendex, Current Contents)					
World Wide Web					
Other (describe)					

8. How would you rate the importance of the following in reducing O&M materials-related costs?

	High	Moderate	Low	None	Don't Know
Life extension of existing equipment					
Service life prediction					
Better methods for in-situ coating application					
Better non-destructive testing and monitoring techniques					
Optimization of currently available materials and technologies					
Development of new materials and technologies					
Education/training					

9. List O&M materials-related research needs in order of priority that you believe would have the greatest impact on improving materials performance, enhancing efficiency and reducing O&M costs.

10. Do you have any other comments?